

**ARRANGEMENT FOR PREDICTING AN ABNORMALITY OF A SYSTEM  
AND FOR IMPLEMENTING AN ACTION OPPOSING THE  
ABNORMALITY**

7 INS A<sub>1</sub>

5 The invention is directed to an arrangement for predicting an abnormality of a system and for the implementation of an action opposing the abnormality.

Description of the Related Art

The determination of an information flow of a system is known from [1] and/or [2]. INS A<sub>2</sub>

10 The information flow characterizes a loss of information in a dynamic system and describes decaying statistical dependencies between the entire past and a point in time that lies  $p$  steps in the future as a function of  $p$ . Among other things, the utility of <sup>such an</sup> the information flow is <sup>described in these references</sup> comprised therein that a dynamic behavior of a complex system can be classified, <sup>allowing</sup> this leading thereto that a suitable parameterized model <sup>to be</sup> is found that enables a modelling of data of the complex dynamic system.

15 A neural network and the training of a neural network are known from [3]. INS A<sub>3</sub>  
Summary of the invention  
The object of the invention is <sup>to provide</sup> comprised in specifying an arrangement that, <sup>then</sup> first, enables a prediction of an abnormality of a system and implements an action opposing the abnormality.

This object is achieved according to the features of patent claim 1. INS A<sub>4</sub>

20 An arrangement for predicting an abnormality of a system and for implementing an action opposing the abnormality is inventively recited. <sup>that has a</sup> A measured data pick-up is <sup>provided therein</sup> provided therein that determines measured data of the system. A processor <sup>implements</sup> unit is configured such that the following steps are implemented:

- 25
- (1) a neural network is trained on the basis of the measured data;
  - (2) the information flow of the system is <sup>used</sup> employed in order to make a prediction about anticipated measured data;
  - (3) when the prediction indicates that the abnormality of the system is anticipated, the action is implemented;

<sup>INS A<sub>5</sub></sup> An actuator that implements the action is <sup>thereby provided</sup> thereby provided dependent on the respective application.

20 B1  
 A goal of the invention is <sup>to provide</sup> a systematic approach to the general problem ~~and,~~  
~~as a solution of this general problem derived therefrom, the determination of a quantity~~  
 (referred to below as prediction quantity) that is suitable for predicting dynamic events  
 of a system. The early recognition of a pattern that represents an <sup>abnormality in</sup> ~~attack on~~ a "normal"  
 5 behavior of the system is of great significance, as, among other things, the following  
 applied examples document.

The applied strategy is divided into *three* steps:

1. The dynamically characterizing features of the system are extracted and  
 adaptively learned (trained). The measure for learning the dynamics of the  
 10 system in this dynamic learning phase should <sup>be general enough</sup> ~~adequately general~~ in order to  
 correspond to stationary as well as non-stationary conditions. The  
 dynamic learning phase is also used in order to demarcate a normal  
 condition of the system from an abnormal condition (abnormality).
2. At least one variable (prediction quantity) is determined with which the  
 15 abnormality is successfully described.
3. As soon as an occurrence of the abnormality is indicated, the information  
 of the impending abnormality is used in order to oppose the impending  
 abnormality via an actuator whose job is to restore the dynamic system into  
 the normal condition. <sup>one also considers</sup> ~~it is thereby to be taken into consideration~~ that the  
 20 normal condition is subject to a natural modification over the course of  
 time, <sup>this is</sup> ~~this being~~ taken into consideration by adaption, i.e., continued training  
 of the neural network, even after the learning phase.

One development <sup>endlessly loops through</sup> ~~is comprised therein that~~ the steps (2) and (3) of the  
 processor unit ~~form an endless loop.~~

25 Another development of the invention is <sup>deals all the situation where</sup> ~~comprised therein that~~ the  
 predetermined abnormality is an information flow with a dynamic <sup>value</sup> below a prescribable  
 threshold. In this case, the action can be <sup>comprised of</sup> ~~comprised in~~ supplying the system with noise.  
 It is possible to deliver <sup>this noise</sup> ~~the noise~~ on the basis of a corresponding electrical field or a  
 corresponding magnetic field. Both the electrical field as well as the magnetic field can  
 30 <sup>using</sup> ~~thereby~~ be supplied to the system ~~on the basis of~~ at least one electrode.

An additional improvement <sup>deals w/ a situation where</sup> is comprised therein <sup>value</sup> that the predetermined abnormality is an information flow having a dynamic above a predetermined threshold.

<sup>ANS</sup> ~~Reaction thereto can be such that the system is excited with a regular signal. This can~~  
<sup>using</sup> ensue ~~on the basis~~ of an electrical or magnetic field. The electrical field and/or the  
 5 magnetic field can be respectively supplied to the system on the basis of at least one electrode.

In the framework of another development, it is also possible to utilize an electrical and a magnetic field in combination in order to oppose the abnormality.

<sup>FNS AG</sup> ~~Developments of the invention also derive from the dependent claims.~~  
<sup>Brief Description of the Drawings</sup>  
 10 Exemplary embodiments of the invention are presented in greater detail on the basis of the following Figures.

~~Shown are:~~  
 Figure 1 <sup>is a block diagram showing</sup> an arrangement for predicting an abnormality of a system and for  
 implementing an action opposing the abnormality;  
 15 Figure 2 <sup>is a block diagram showing</sup> an actuator AKT2 <sup>an</sup> active component, composed of a computer R, an  
 interface IF, an energy store BT and two electrodes EL1 and EL2;  
 Figure 3 <sup>is a flowchart showing</sup> steps of a method for ~~the~~ implementation on a processor unit.  
<sup>Description of the Preferred Embodiments</sup>  
 Figure 1 shows an arrangement for predicting an abnormality of a system  
 and for implementing an action opposing the abnormality.

20 The measured data pick-up MDA registers measured data of a system S.  
 To this end, the measured data pick-up MDA is preferably arranged within the system  
 S in order to register the measured data on site. The measured data are conducted to a  
 processor unit PRE <sup>where they are processed</sup> and ~~processed thereat~~. The processor unit PRE preferably  
 comprises a neural network NN that, following training, suitably interprets further  
 25 measured data registered by the measured data pick-up MDA. When there are  
 indications that an action is to be implemented due to the measured data, an actuator  
 AKT is initiated by the processor unit PRE to implement a predetermined action. The  
 actuator preferably comprises at least one electrode that is directly driven by the  
 processor unit PRE.

~~Let it thereby be noted that the~~ <sup>the</sup> processor unit is arranged in the system S', as indicated in Figure 1 on the basis of the broken line and the appertaining designation of the system S'.

The system S preferably comprises the measured data pick-up MDA and/or  
5 the actuator AKT in order to respectively assure a direct access of the measured data pick-up MDA to the measured data and of the actuator AKT to the system.

Figure 2 shows a differently constructed actuator AKT 2. ~~Via the interface~~ <sup>via the interface 201</sup>  
~~201, this~~ <sup>this</sup> actuator AKT2 likewise receives a signal from the processor unit PRE that informs a computer R, which is part of the actuator AKT2, that a predetermined action  
10 is to be implemented. ~~Further,~~ <sup>furthermore</sup> an energy store BT is provided in the actuator AKT2, ~~this~~ <sup>this</sup> energy store BT, controlled by the computer R, ~~applying~~ <sup>applies</sup> energy to the electrodes EL1 and EL2 in a suitable way. The computer R of the actuator AKT2 thereby controls the interface IF in order to preferably determine amplitude and frequency of the energy applied to the electrodes EL1 and EL2.

15 Figure 3 shows steps of the method implemented by the processor unit PRE.

<sup>ANS A9</sup> A neural network NN is trained in a step 301. To this end, measured data of a suitable scope are prescribed in order -- following the training -- to be able to make a statement as to whether new measured data indicate an abnormality of the  
20 system. After the end of the training, an information flow (see [1] or [2]) is evaluated on the basis of current data in a step 302. An abnormality of the system can be indicated on the basis of this information flow before the occurrence of this abnormality. The abnormality is predicted in a step 303; an action that opposes an occurrence of the abnormality is implemented in a step 304. Subsequently, a branch is  
25 preferably made to the step 302.

Two applied examples follow, ~~these~~ <sup>that illustrate</sup> illustrating the possibilities of a prediction of an abnormality.

### Application 1: Electrocardiogram (ECG) Data

One application relates to the possible prediction of a fibrillating heart. The abnormality <sup>occurs when</sup> ~~is comprised therein~~ that the heart beats nearly chaotically.

ECG measured data are inventively employed in order to learn the dynamics of a heart of a patient <sup>the</sup> (training phase of the neural network NN). ~~It should~~ <sup>The</sup> ~~thereby be noted that the~~ dynamics of the heart vary greatly dependent, for example, on the time of day and the activity in which a person is engaged <sup>at a particular</sup> ~~at the moment~~. Invariable quantities (prediction quantity) that significantly describe the dynamics of the heart of <sup>a person</sup> ~~the person~~ despite great variation <sup>are</sup> ~~should~~ nonetheless be determined. A variation of the prediction quantity enables the prediction of an abnormality of the heart. A control mechanism that restores the normal heart rhythm is started upon recognition of the abnormality.

The prediction quantity represents an imaging of a sudden variation of the complexity of the dynamics, and the actuator is realized in the form of an electrode that delivers small electrical pulses to the heart.

### Application 2: Electroencephalogram (EEG) Data

The brain, <sup>e.g. a human brain</sup> ~~preferably the human brain~~, is another dynamic system. When it is assumed that EEG measured data represent brain activity, one task is to suitably interpret the signals and potentially link predetermined measures <sup>to them. An</sup> ~~thereto. Thus, an~~ epileptic attack is characterized by a synchronous firing of a group of neurons that are arranged centered around a mid-point. This synchronism reduces the complexity of the dynamics of the brain and is indicated by EEG measured data. In contrast <sup>to this</sup> ~~thereto~~, the normal condition, ~~i.e.~~ the normally working brain, represents a condition of irregularly firing neurons.

The early recognition of an epileptic attack becomes possible by determining a continued simplification of the dynamics of the brain. The actuator for restoring the normal condition has the job of opposing this synchronism that is apparently responsible for the epileptic attack. This preferably occurs by applying a field, as explained in greater depth below.

<sup>The</sup> ~~We shall turn to the~~ second applied example for avoiding an epileptic attack below for further reaching comments. <sup>INS A10</sup>

### The Dynamic Prediction Quantity

The idea is comprised in the expansion of the statistical approximation according to <sup>Schrittenkopf</sup> [2] for detecting a Markov character in which a given empirical time row is inherent. One objective is to separate a deterministic part <sup>from</sup> a stochastic part of a dynamic system in the <sup>area of</sup> ~~surround of the~~ statistical test theory in that the information flow of the system is analyzed. The statistical development of the dynamics is tested against a hierarchy of zero hypotheses that correspond to non-linear Markov processes with increasing order  $n$ . These processes are divided into a deterministic part and a stochastic part in the following way:

10 
$$x_t = f(x_{t-1}, \dots, x_{t-n}) + u \quad (1),$$
  
~~where~~ <sup>where</sup>  $u$  indicates an additive noise distributed according to Gauss with the variance  $\sigma^2$ ,  $x_t$  indicates a measured datum at the time  $t$  and  $f(\cdot)$   <sup>$x_{t-1}, \dots, x_{t-n}$</sup>  indicates a deterministic part.

The Markov process with the order  $n$  is defined by the conditioned probability densities thereof

$$p(x_t | x_{t-1}, \dots, x_{t-n}) \propto \exp\left(-\frac{[x_t - f(x_{t-1}, \dots, x_{t-n})]^2}{2\sigma^2}\right) \quad (2)$$

15 The deterministic part is implemented by a neural network NN that is trained according to the maximum likelihood principle <sup>in A1</sup> [4] applied to the probability densities according to Equation (2). The stochastic part  $u$  is described by noise distributed according to Gauss, <sup>where</sup> ~~whereby~~ the variance  $\sigma^2$  is referred to a defined, mean last ~~[sic]~~ quadratic error. In other words, the zero hypotheses contain not only the order of the Markov process but also an actual deterministic structure. When a chaotic condition is present, thus, the order of the accepted zero hypothesis is the EED (effective embedding dimension). This approach opens up a method for determining the EED, whereas temporary measured data are modelled parallel <sup>to it</sup> ~~thereto~~.

25 This approach also allows a strict expansion of the concept of ED (embedding) when a chaotic condition prevails. The express determination of the deterministic part is a method for filtering the noise out of the time row.

The zero hypothesis is implemented with a method described in <sup>Schrittenkopf</sup> [2].

As known from <sup>Deo Schittenkopf</sup> [1] and [2], an information flow, i.e., a non-parametric criterion of a predictable development, is used as a discriminating statistic. A significance test is ~~thus~~ <sup>where</sup> implemented for every point in time to be predicted, ~~whereby~~ the zero hypothesis (i.e., a given assumption that is to be checked) is only accepted  
 5 when the significance test is met for all quantities of the point in time to be predicted.

### Analysis of Human Epilepsy Attacks

As described above, one application of the invention is represented by the analysis of EEG measured data in order to prevent an epileptic attack. One goal is ~~to test~~ <sup>in the analysis</sup> ~~thereby to test~~ whether a dynamic classification of the measured data for time windows  
 10 of different size can be used as prediction quantities in order to predict an epileptic attack. In particular, two prediction quantities are recited:

- a) The "reminder" of the underlying dynamics, i.e., the EED (see the above comments);
- b) a non-parametric criterion for a predictability, defined by the  
 15 integration of the information flow.

The approach presented here does not assume that the underlying dynamics are chaotic (even if they could be); rather, the emphasis lies on the time span preceding the epileptic attack in order to define a prediction quantity for the epileptic attack that is based on the dynamics of the system.

### 20 Control of the Epileptic Attack

An epileptic attack can be suppressed in that a constant electrical field is supplied to the regions that are affected by the epileptic attack (see <sup>INSA 12</sup> [5]).

According to an assumption that the normal condition of the brain is marked by chaotic dynamics, an epileptic attack is expressed by a drastic simplification  
 25 of the dynamics in the brain. The epileptic attack is countered in that the reduction of the dynamics, i.e., the synchronicity is, as described above, opposed in that a noise is supplied to the system, ~~the brain in this case~~ <sup>the brain, in this case</sup>.

The delivery of this noise is preferably generated by applying an electrical field or a magnetic field in the immediate environment of (as close as possible to) the location of the action. Electrodes for generating an electrical field or coils for generating a magnetic field are preferably employed for this purpose. The

5 synchronously firing neurons in the epileptic attack have their synchronicity disturbed by the electrical and/or magnetic field; a (seemingly) chaotic firing of the neurons is re-established in the brain, <sup>and</sup> the epileptic attack has thus been averted.

It is ~~thus~~ fundamentally important that a suitable reaction is carried out in response to an abnormal behavior of a dynamic system, <sup>STATUS</sup> whereby the abnormal

10 behavior is detected with a prediction quantity. <sup>dependent on</sup> ~~Dependent on~~ the field of employment, this reaction <sup>may be</sup> ~~is comprised~~, for example, ~~in~~ <sup>field</sup> generating a chaotic or in generating a regular field. This action, which is implemented by the actuator, is dependent on the respective field of employment. What the various versions of the method respectively have in common is a dynamic learning, <sup>in which</sup> whereby a significant abnormality is allocated

15 to a prediction quantity and this prediction quantity enables a detection of an impending abnormality. <sup>the methods then</sup> ~~It is thereby expedient to implement~~ a suitable action with the actuator within a predetermined time interval preceding the occurrence of the abnormality <sup>of the epileptic seizure or of the chaotically beating heart</sup>. The prediction quantity thus enables the recognition of an abnormality before <sup>this abnormality</sup> ~~this~~ actually

20 occurs.

Since the entire system changes over a longer time span in view of its dynamically normal property, an adaption of the originally learned dynamic system is <sup>necessary</sup> ~~expedient~~. It is important to define the prediction quantity in that the data significantly characterizing an abnormality are imaged from the entire dynamic system in the

25 prediction quantity. A prediction of the abnormality can thus ensue even given a dynamic system subject to great fluctuations, for example, a heart that is subjected to <sup>a great</sup> ~~the greatest~~ variety of stresses, <sup>and where</sup> ~~whereby~~ one of these stresses does not necessarily indicate an abnormality.

STATUS AHA



The following publications were cited in the framework of this document:

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10 Computing", Springer-Verlag, 1996, Chapter 7.2.
- [5] B. Gluckmann, E. Neel, T. Netoff, W. Ditto, M. Spano, S. Schiff, "Electric field suppression of epileptiform activity in hippocampal slices", Journal of Neurophysiology 76, pages 4202-4205, 1996.